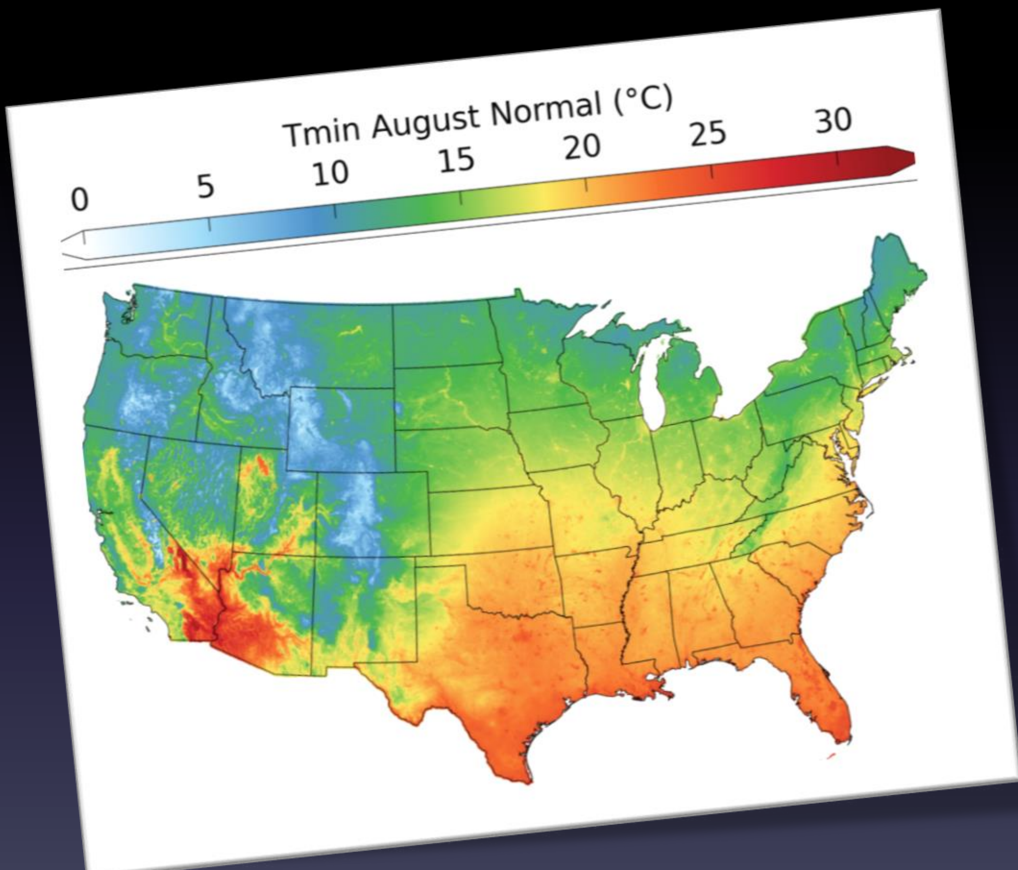
A Topoclimatic Air Temperature Dataset for the Conterminous U.S.



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ET Workshop

May 29, 2015

UNIVERSITY OF MONTANA

Montana Climate Office

Outline

- Overview of existing topoclimate datasets
- Motivations for creating a new topoclimatic temperature dataset
  - **TopoWx**
  - 1948 to present daily Tmin and Tmax at ~800m resolution
- TopoWx methods
  - Station observation homogenization
  - MODIS land skin temperature
  - Moving window regression kriging
- Analysis of TopoWx temperature outputs
  - Spatial component (1981-2010 normals)
  - Temporal component (trends)
- Conclusions

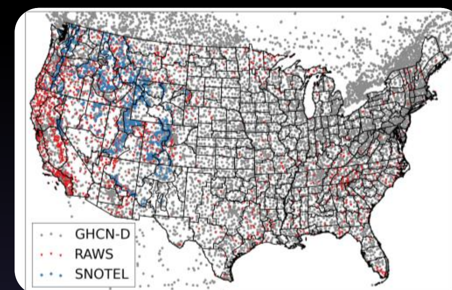
Topoclimatic Temperature Datasets

"**Topoclimatic modeling** refers to spatial estimates of climate that take into account topographic position in the landscape" (*Dobrowski et al.,* 2009).

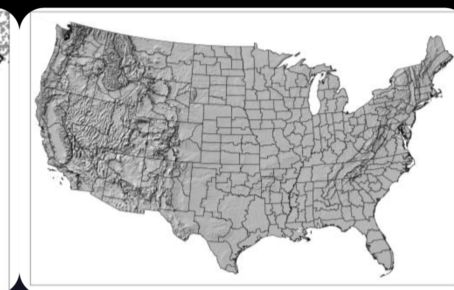
Interpolated Topoclimatic Datasets: use point-source weather station data and a DEM to incorporate the effects of topoclimatic factors and statistically interpolate climate variables to a regular grid (800-m to 12-km).

- PRISM (*Daly et al.* 2008)
- Daymet (*Thornton et al.* 1997)
- UW (*Maurer et al. 2002; Livneh et al. 2013)*

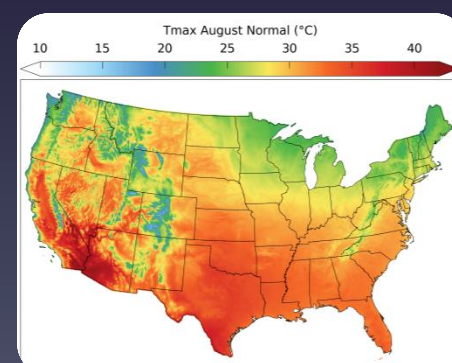
Weather Stations



DEM and DEM-Derived Variables



Interpolated Topoclimatic Dataset



Motivations

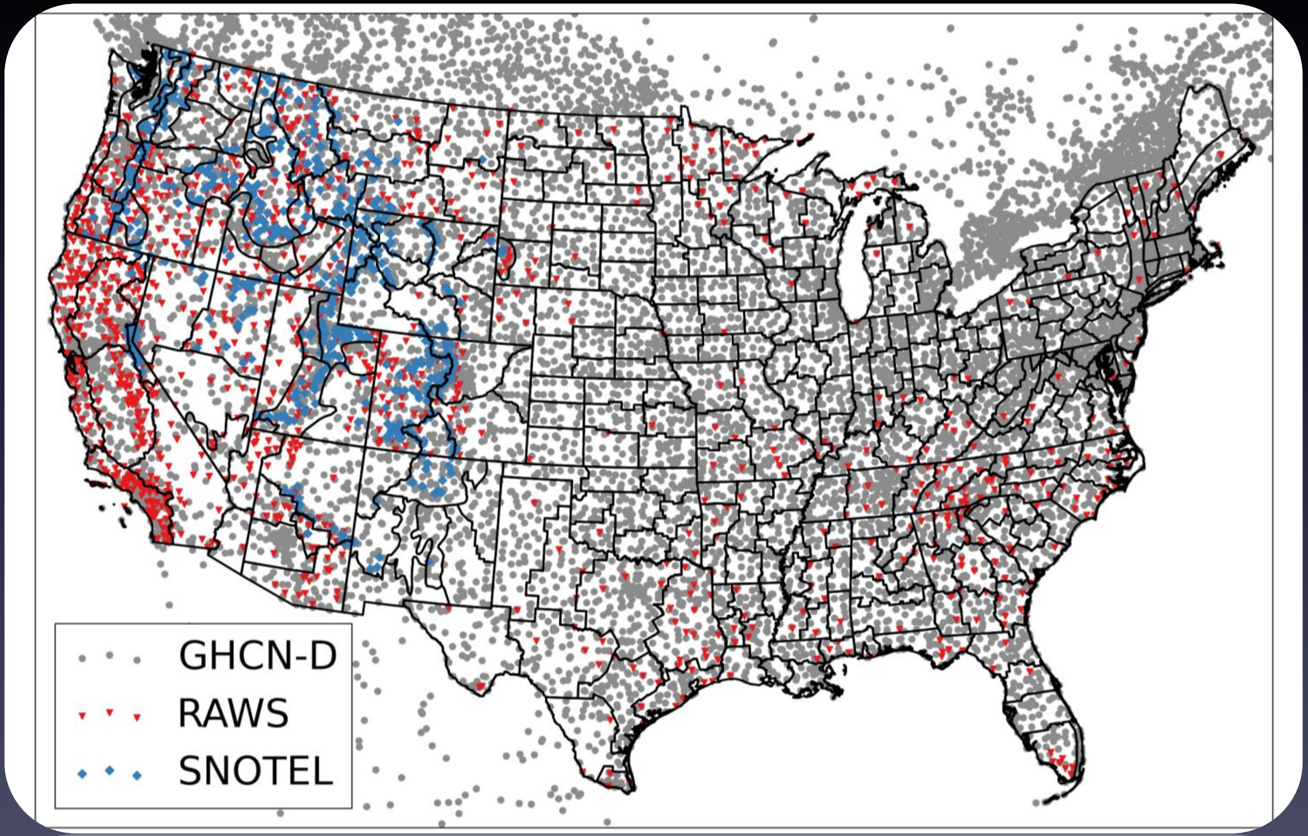
Main motivations for creating new topoclimatic air temperature dataset for CONUS (**TopoWx**):

1. CONUS topoclimate datasets use statistical models strictly driven by DEM-based predictor variables
2. CONUS topoclimate datasets do not homogenize input station data
3. CONUS topoclimate datasets do not provide estimates of spatial uncertainty
4. CONUS topoclimate datasets are proprietary and closed source

TopoWx Methods:
1948-2012 Daily Tmin and Tmax
at 800-m resolution

Input Weather Station Data

- 14,087 input stations
- Each station has >= 5 years of raw data, 1948 – 2012
- GHCN-D QA procedures (*Durre et al.* 2010)



Homogenization

- **Inhomogeneity**: a change in a temperature observation record resulting from non-climatic influences
- **Homogenization**: the detection and removal of inhomogeneities
- **Pairwise Homogenization Algorithm***
  - Statistical homogenization procedure used for USHCN

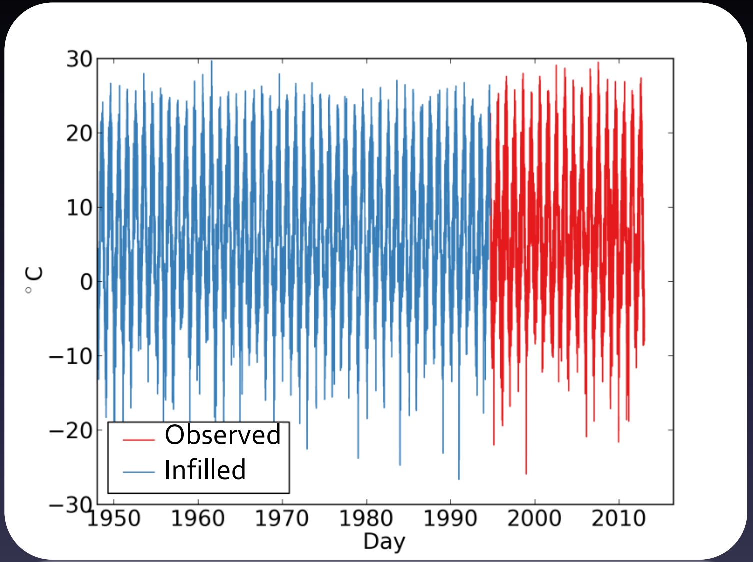
*Menne, M. J., & Williams, C. N. (2009). Homogenization of Temperature Series via Pairwise Comparisons. Journal of Climate, 22(7), 1700–1717. doi:10.1175/2008JCLI2263.1

Missing Observation Infilling

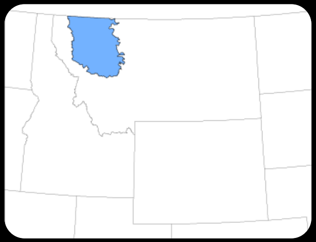
How to handle incomplete 1948-2012 data records and missing data?

- Simply interpolating raw incomplete data could produce inhomogeneities in the gridded output as the number of stations and station spatial coverage vary during the 1948-2012 time period
- Don't want to throw away key observations, (i.e.—SNOTEL, RAWS)
- Expectation maximization and principal component analysis-based infilling of missing station observations using:
  - Long-term stations
  - NCEP/NCAR Reanalysis: temperature, thickness, geopotential height, wind, sea level pressure

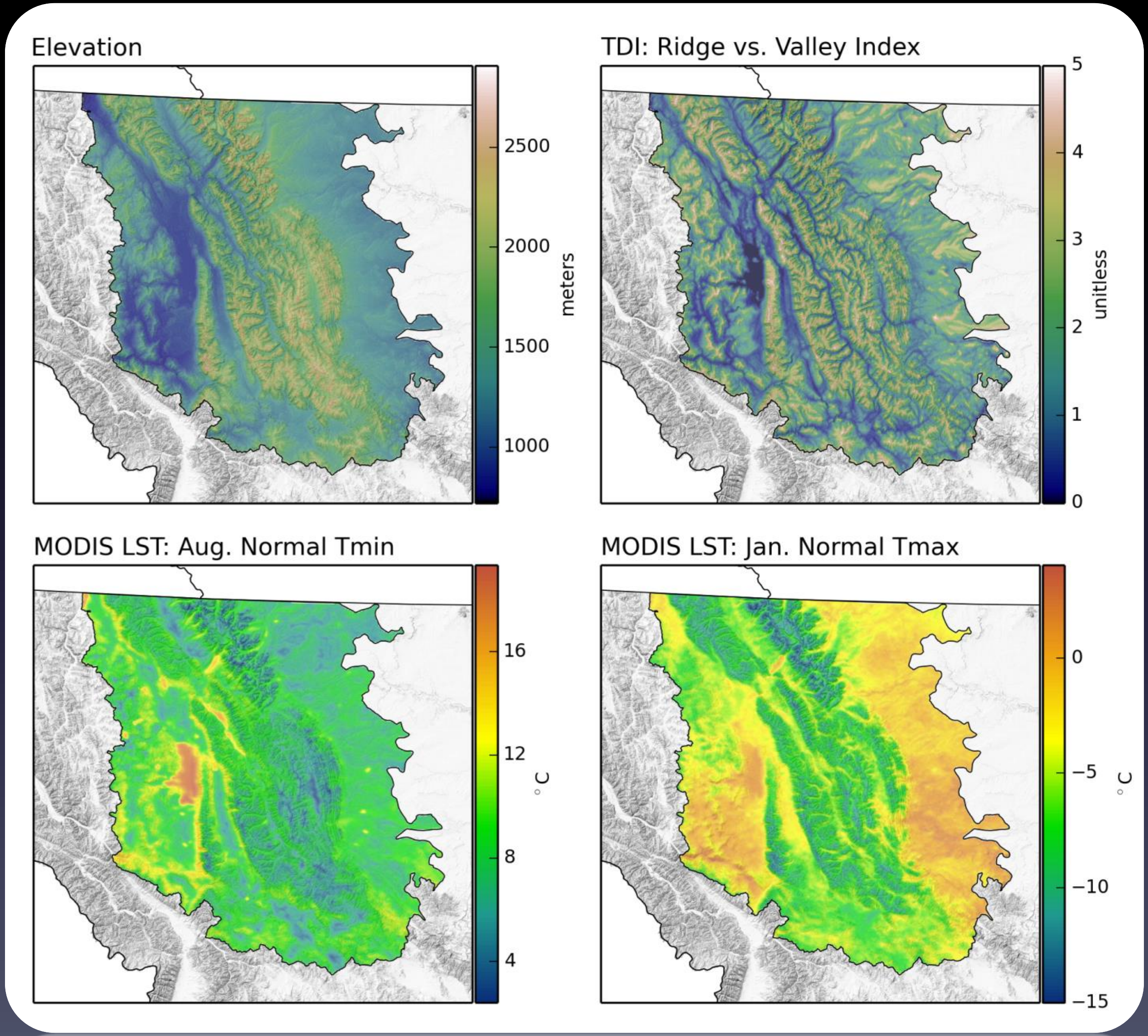
Stuart Peak SNOTEL Tmax
Near Missoula, MT.
Observing since 1994



Interpolation Methods



Crown of the Continent Ecosystem, Montana

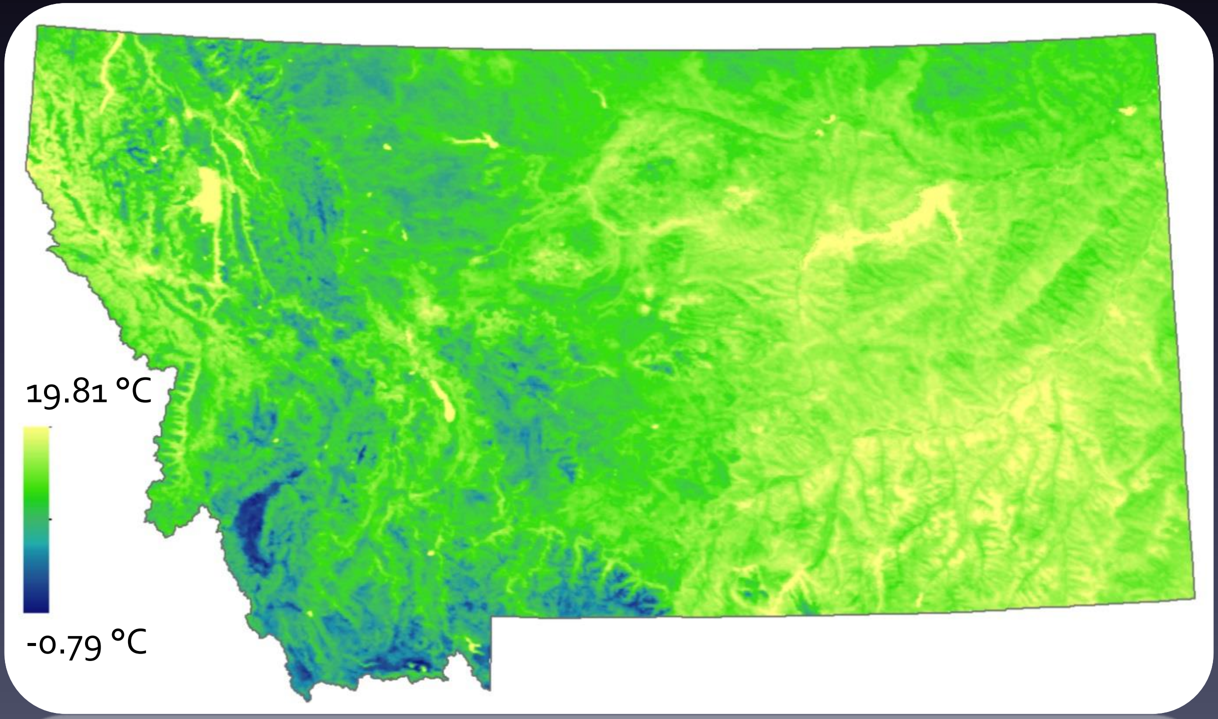


Auxiliary Spatial Predictors of Temperature

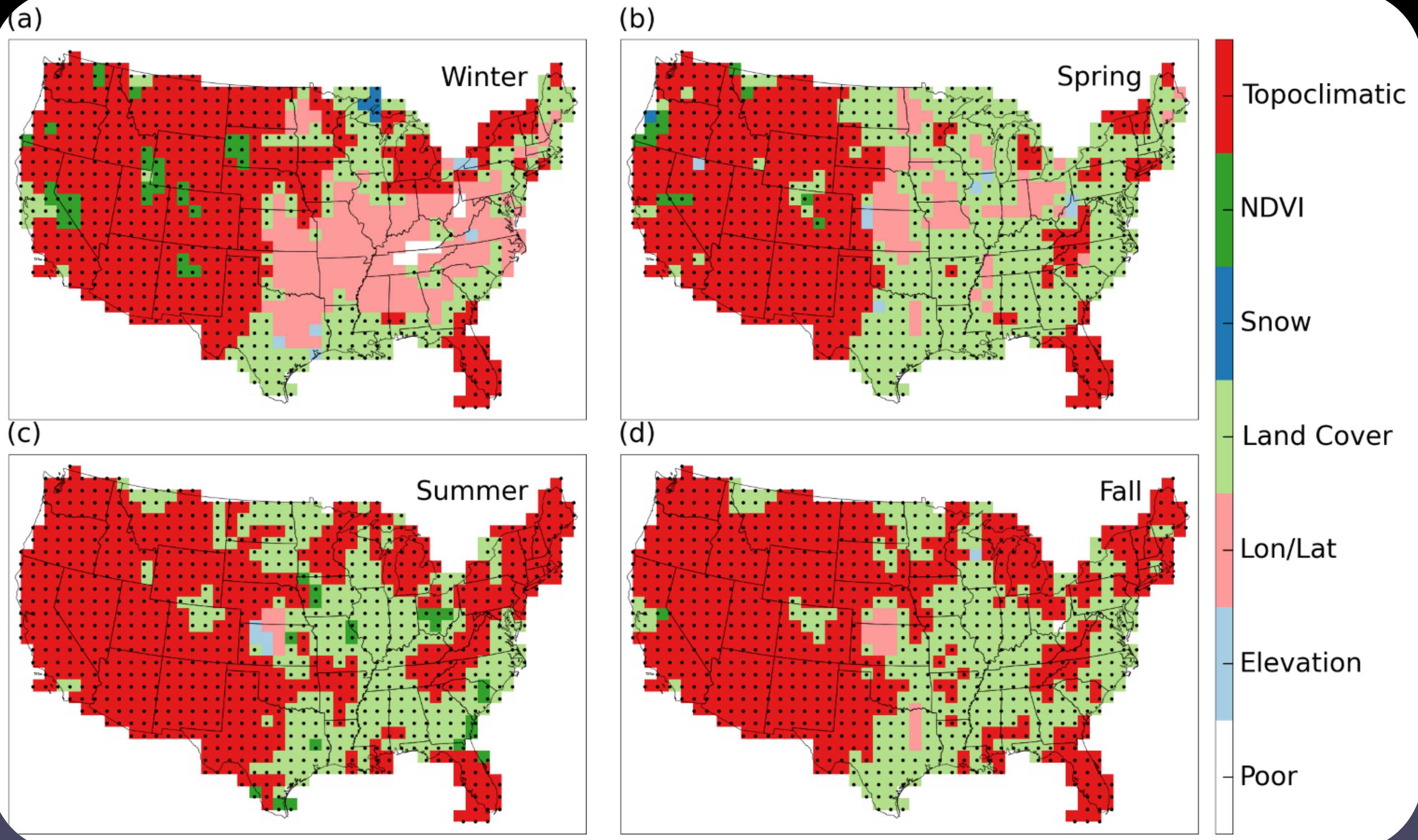
1. Elevation
2. Topographic Dissection Index
3. MODIS Land Skin Temperature

Does MODIS LST capture topoclimatic and land surface biophysical spatial variations crucial for air temperature interpolation or is it redundant with DEM-based predictor variables?

Tmin Avg. Land Skin Temperature: August 2003-2012

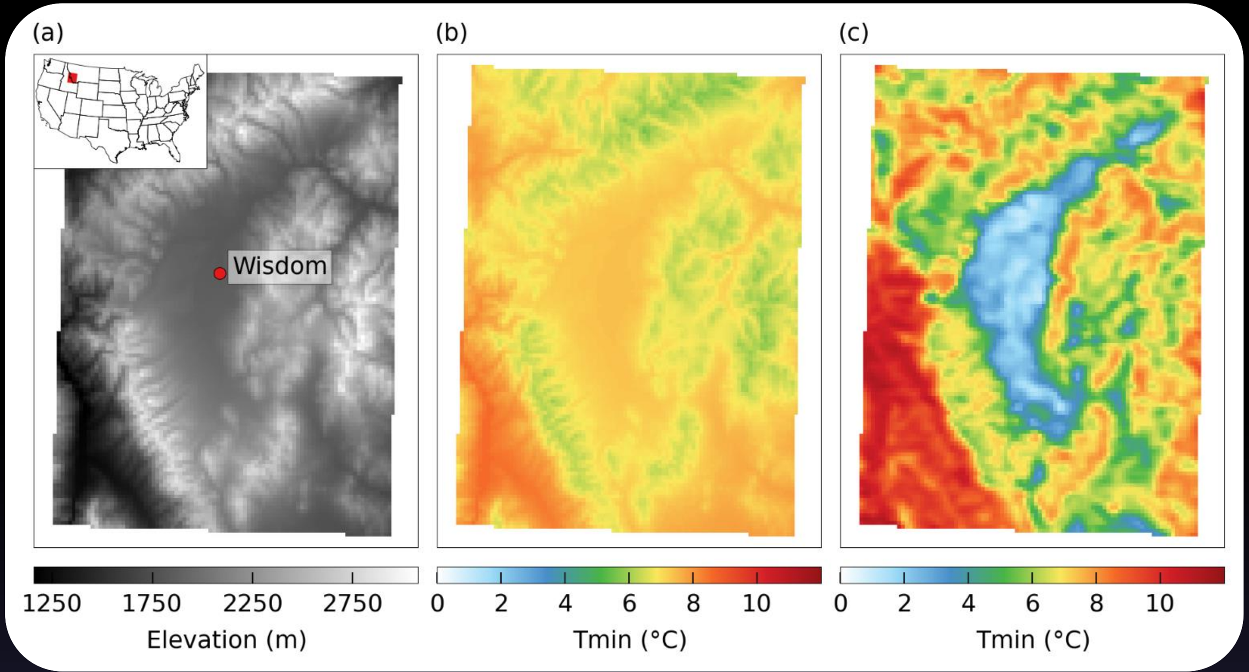


Linear Relationship of Tmin and Nighttime LST

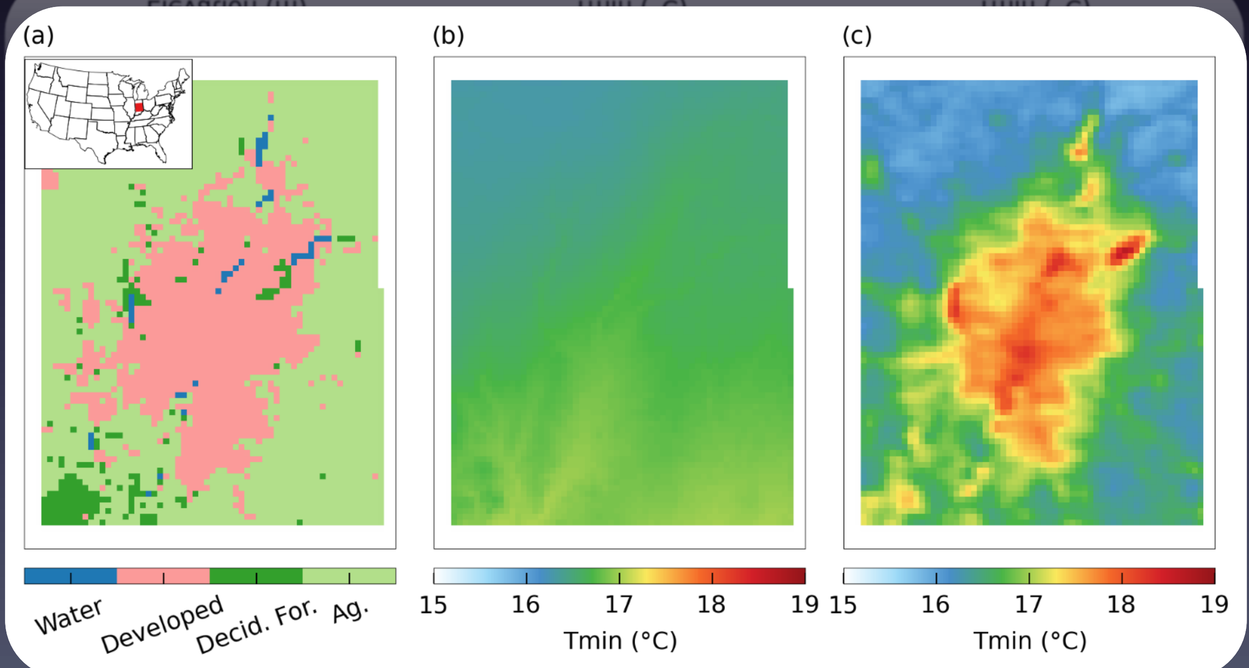


Aug. Tmin

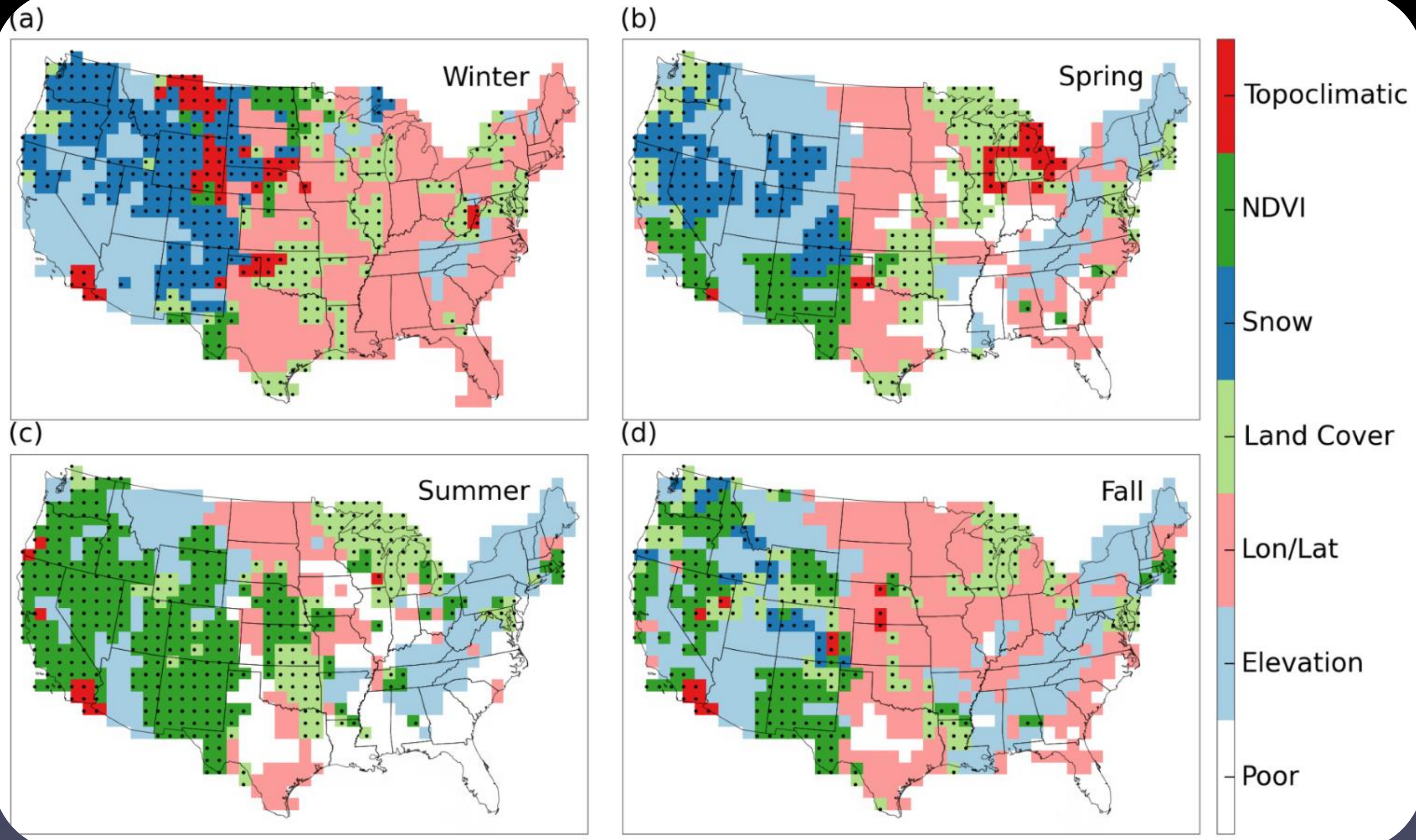
Big Hole, MT

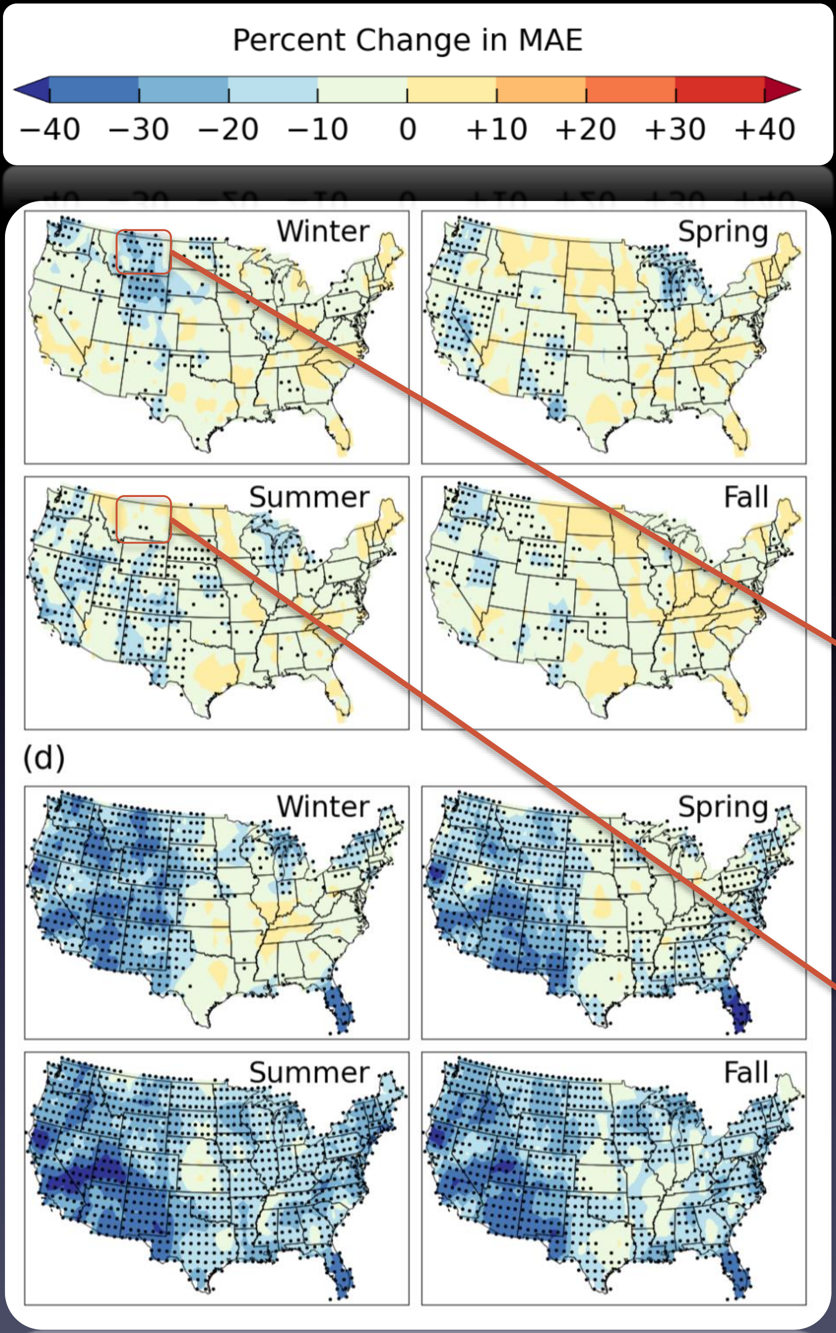


Indianapolis, IN

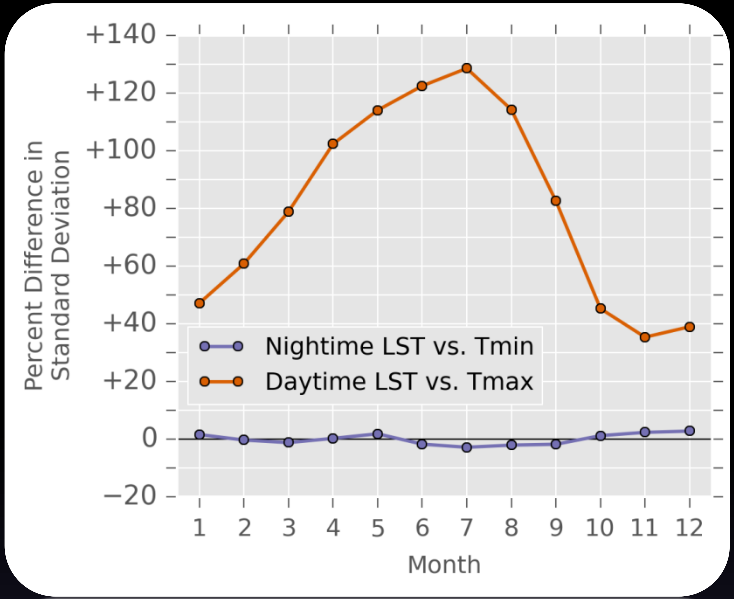


Linear Relationship of Tmax and Daytime LST

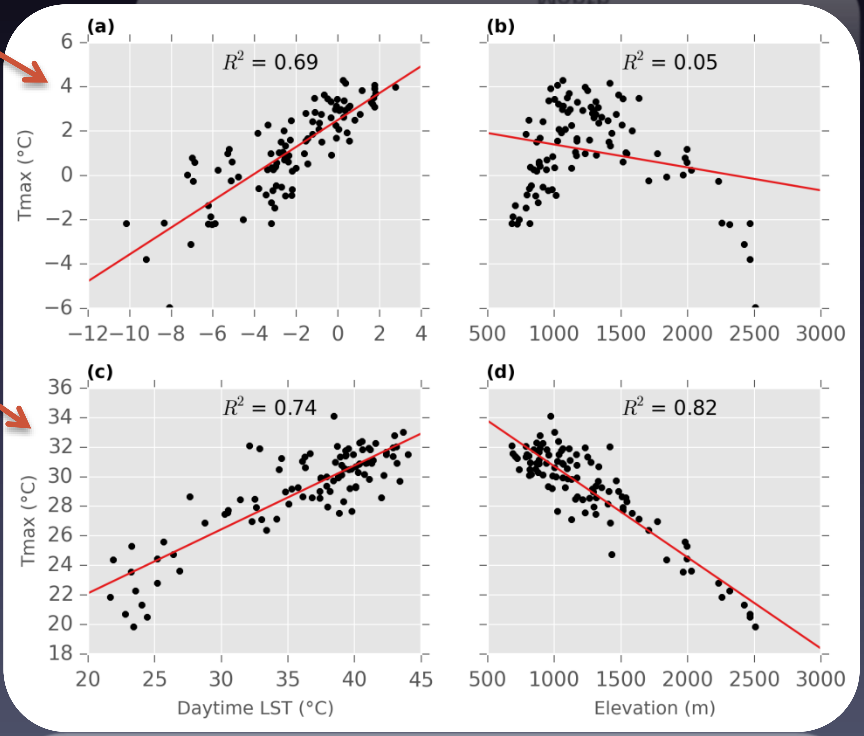




Percent Change in MAE
−40 −30 −20 −10 0 +10 +20 +30 +40
Winter
Spring
Summer
Fall
(d)
Winter
Spring
Summer
Fall



Percent Difference in Standard Deviation
+140 +120 +100 +80 +60 +40 +20 0 −20
Nightime LST vs. Tmin
Daytime LST vs. Tmax
1 2 3 4 5 6 7 8 9 10 11 12
Month



(a)
R^2 = 0.69
(b)
R^2 = 0.05
Tmax (°C)
6 4 2 0 −2 −4 −6
−12 −10 −8 −6 −4 −2 0 2 4
500 1000 1500 2000 2500 3000
(c)
R^2 = 0.74
(d)
R^2 = 0.82
Tmax (°C)
36 34 32 30 28 26 24 22 20 18
20 25 30 35 40 45
Daytime LST (°C)
500 1000 1500 2000 2500 3000
Elevation (m)

Interpolation Methods

Step 1: Interpolate Tmin/Tmax monthly normals (1981-2010) using **Moving Window Regression Kriging**

Deterministic spatial trend in normal temperature

Random spatially autocorrelated residual

$$\bar{T}(s_0, m_0) = \beta_0 + \beta_1 x + \beta_2 y + \beta_3 z + \beta_4 lst(m_0) + \sum_{i=1}^{n} w_i(s_0, m_0) \cdot \bar{T}_e(s_i, m_0)$$

Symbol	Description
$\bar{T}(s_0, m_0)$	Normal temperature for grid cell s_0 and month m_0
x	Longitude
y	Latitude
z	Elevation
$lst(m_0)$	MODIS 10 year (2003-2012) mean land skin temperature for month m_0

Symbol	Description
$w_i(s_0, m_0)$	Weights defined by residual spatial covariance
$\bar{T}_e(s_i, m_0)$	Regression residuals for n stations

Interpolation Methods

Step 2: Interpolate daily Tmin/Tmax anomalies around $\bar{T}$ normals using a daily-varying **Geographically Weighted Regression**

$$\delta T(s_0, d_0) = \beta_0 + \beta_1 x + \beta_2 y + \beta_3 z + \beta_4 lst(m_0) + \beta_5 tdi$$

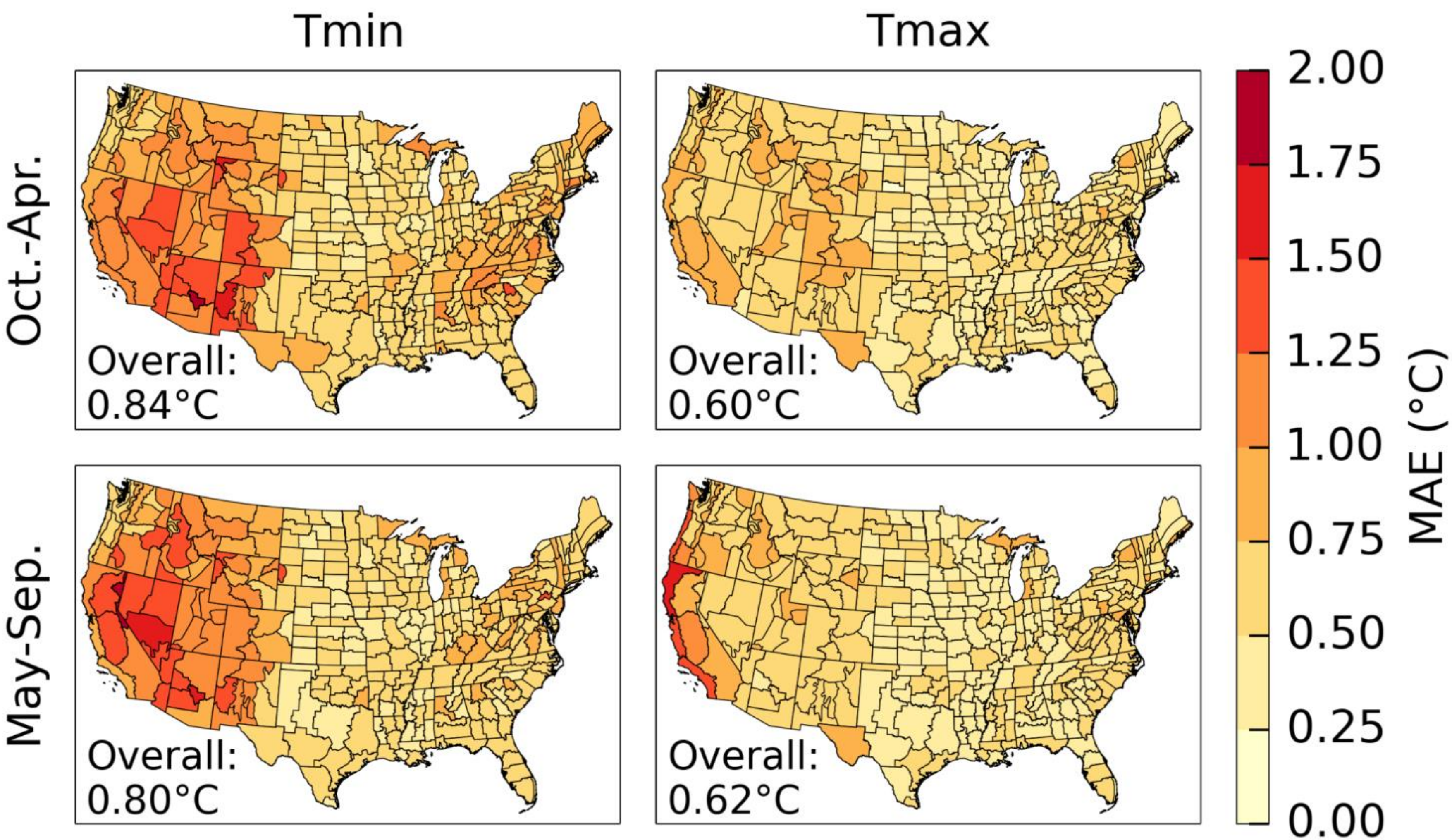
Symbol	Description
$\delta T(s_0, d_0)$	Daily temperature anomaly for grid cell s_0 and day d_0
tdi	Topographic Dissection Index (*Holden et al.* 2011) 0 = deep valley; 5 = ridge/peak

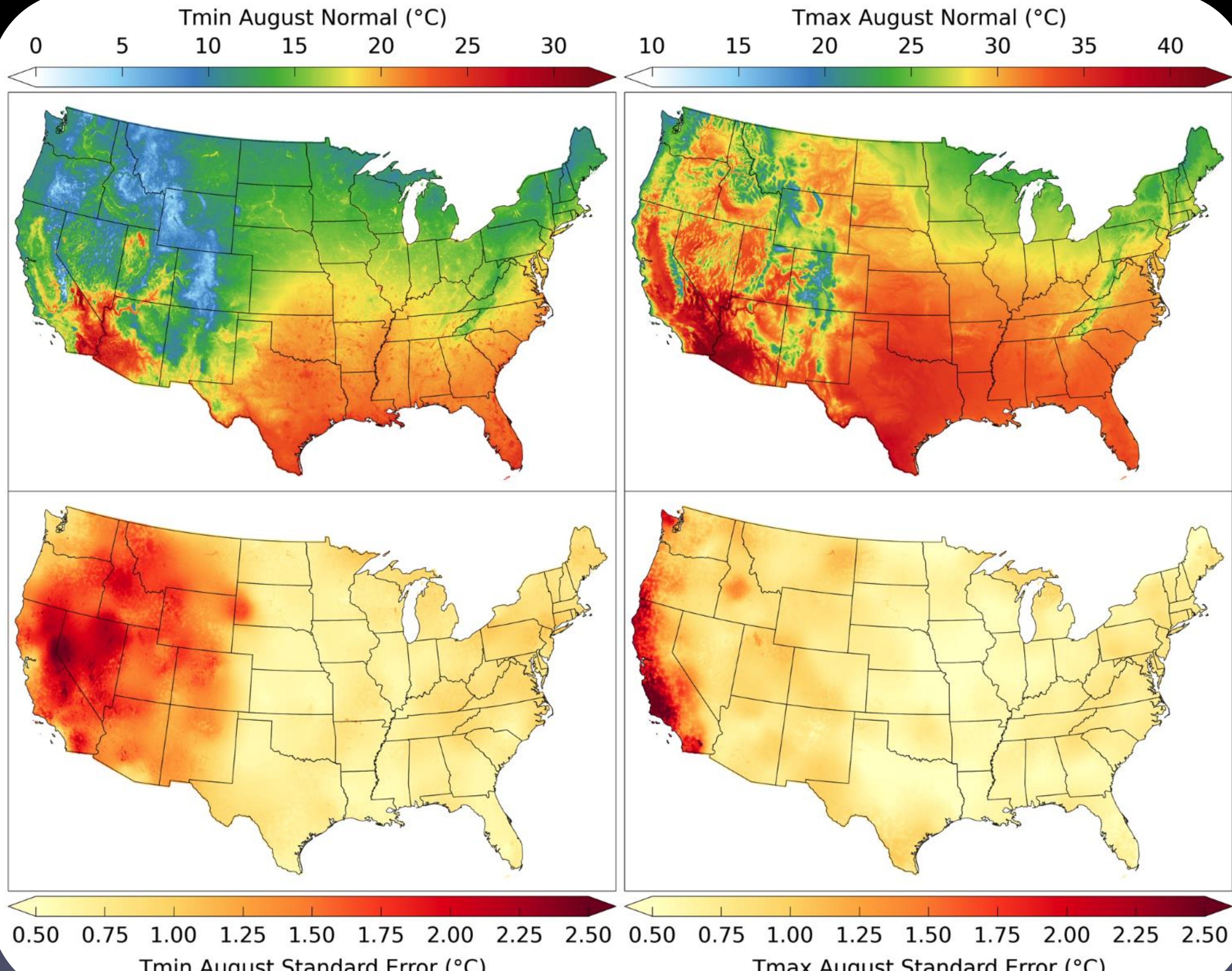
Step 3: Combine monthly normals and daily anomalies to get final 1948-2012 temperature estimates

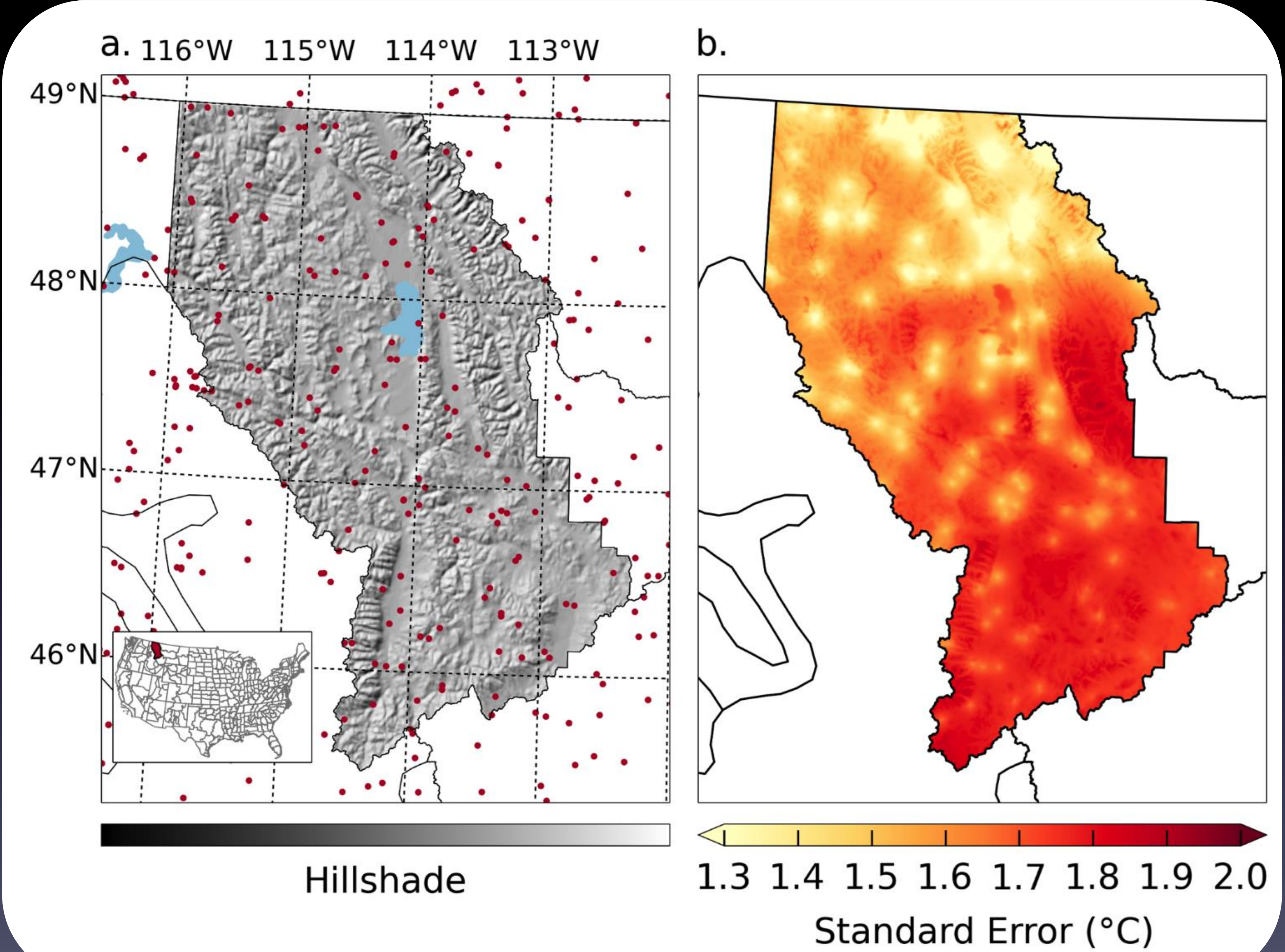
$$T(s_0, d_0) = \bar{T}(s_0, m_0) + \delta T(s_0, d_0)$$

TopoWx Temperature Outputs: 1981-2010 Normals

1981-2010 Monthly Normals
Cross Validation Mean Absolute Error

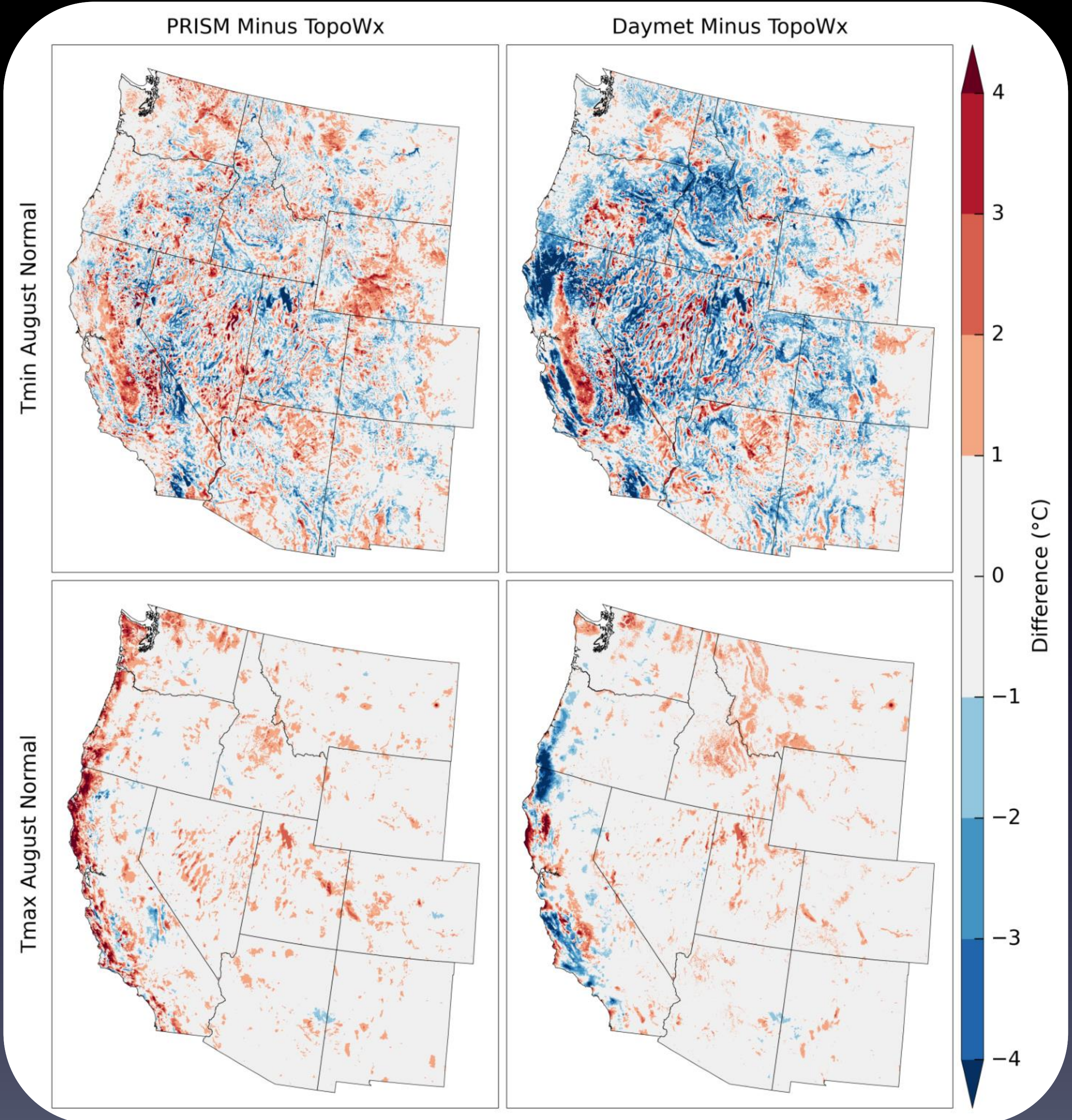



Tmin August Normal (°C)
0 5 10 15 20 25 30
Tmax August Normal (°C)
10 15 20 25 30 35 40
0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50
Tmin August Standard Error (°C)
0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50
Tmax August Standard Error (°C)

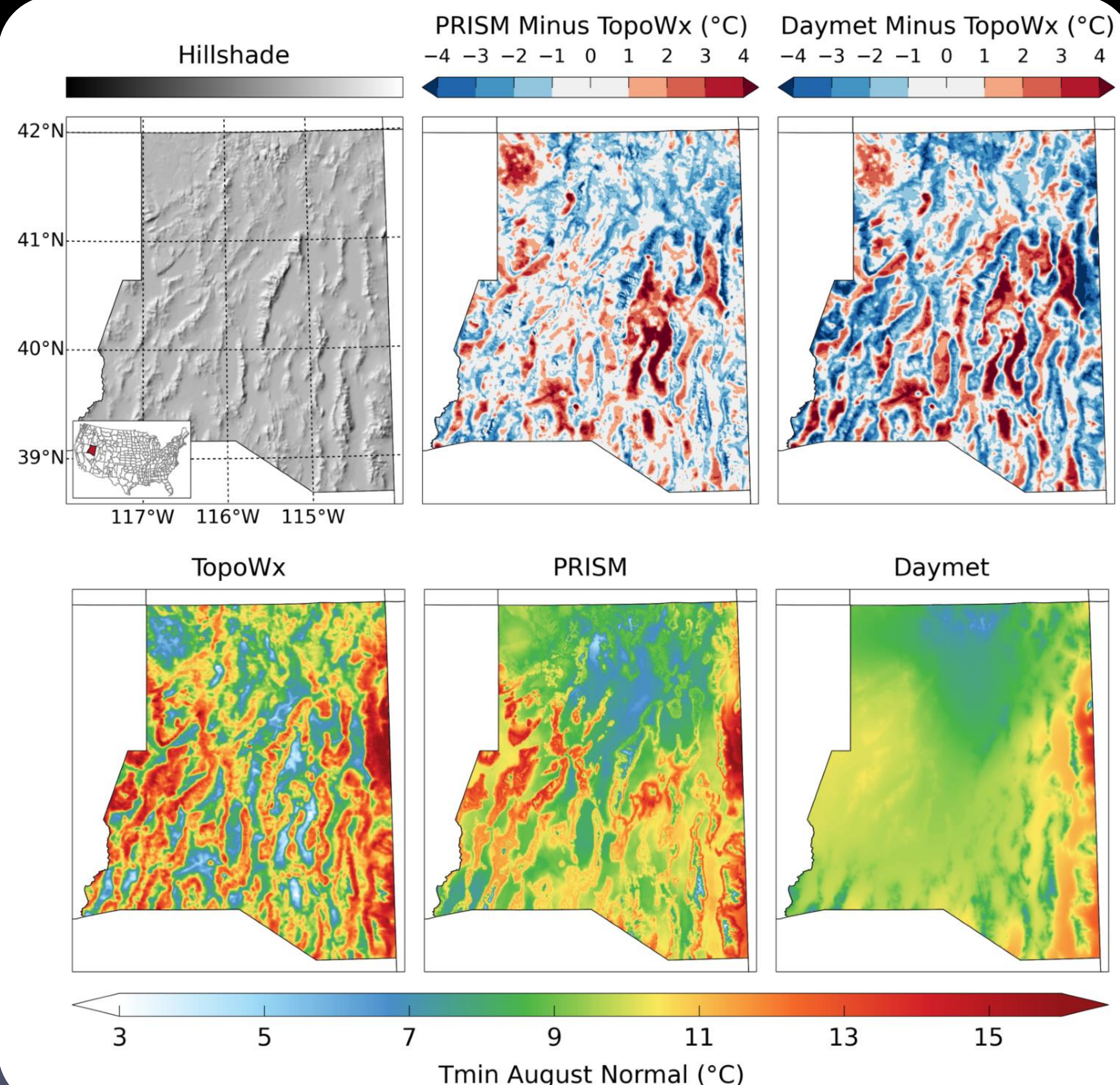


a.
116°W
115°W
114°W
113°W
49°N
48°N
47°N
46°N
Hillshade
b.
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
Standard Error (°C)

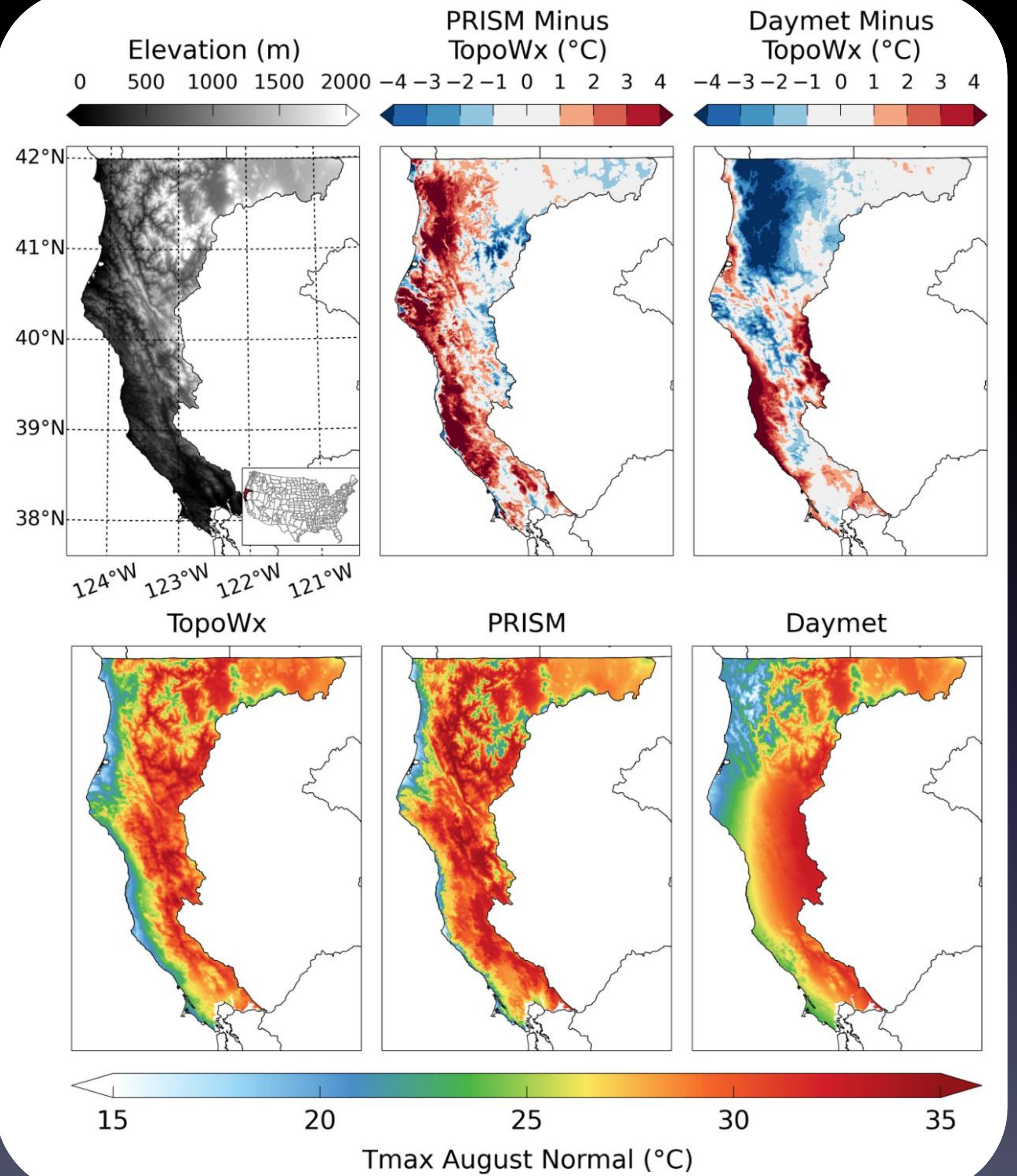
Western U.S. Comparison



Nevada Northeastern Climate Division

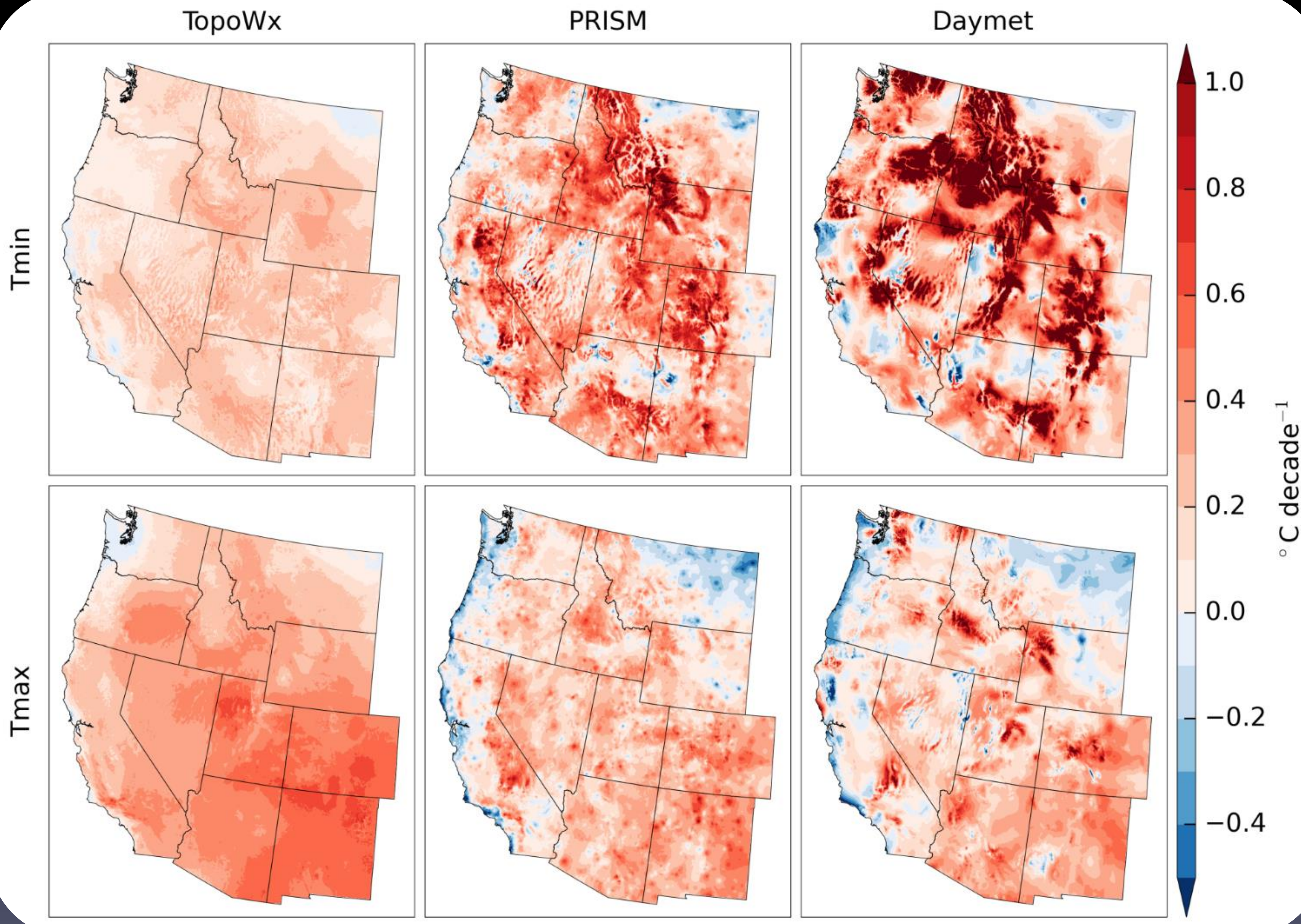


California
North Coast
Drainage
Climate Division

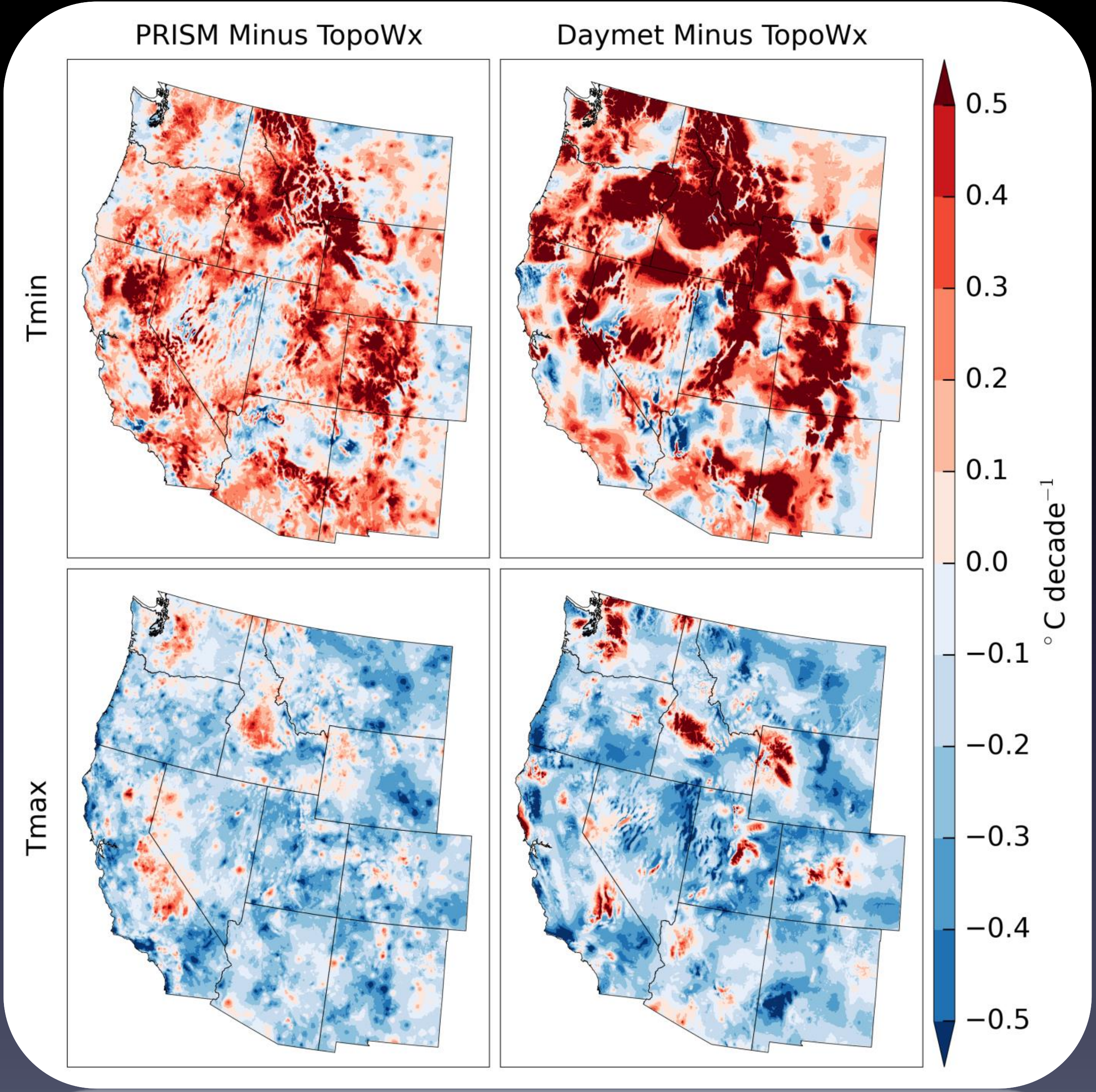


TopoWx Temperature Outputs: Temporal Variability and Trends

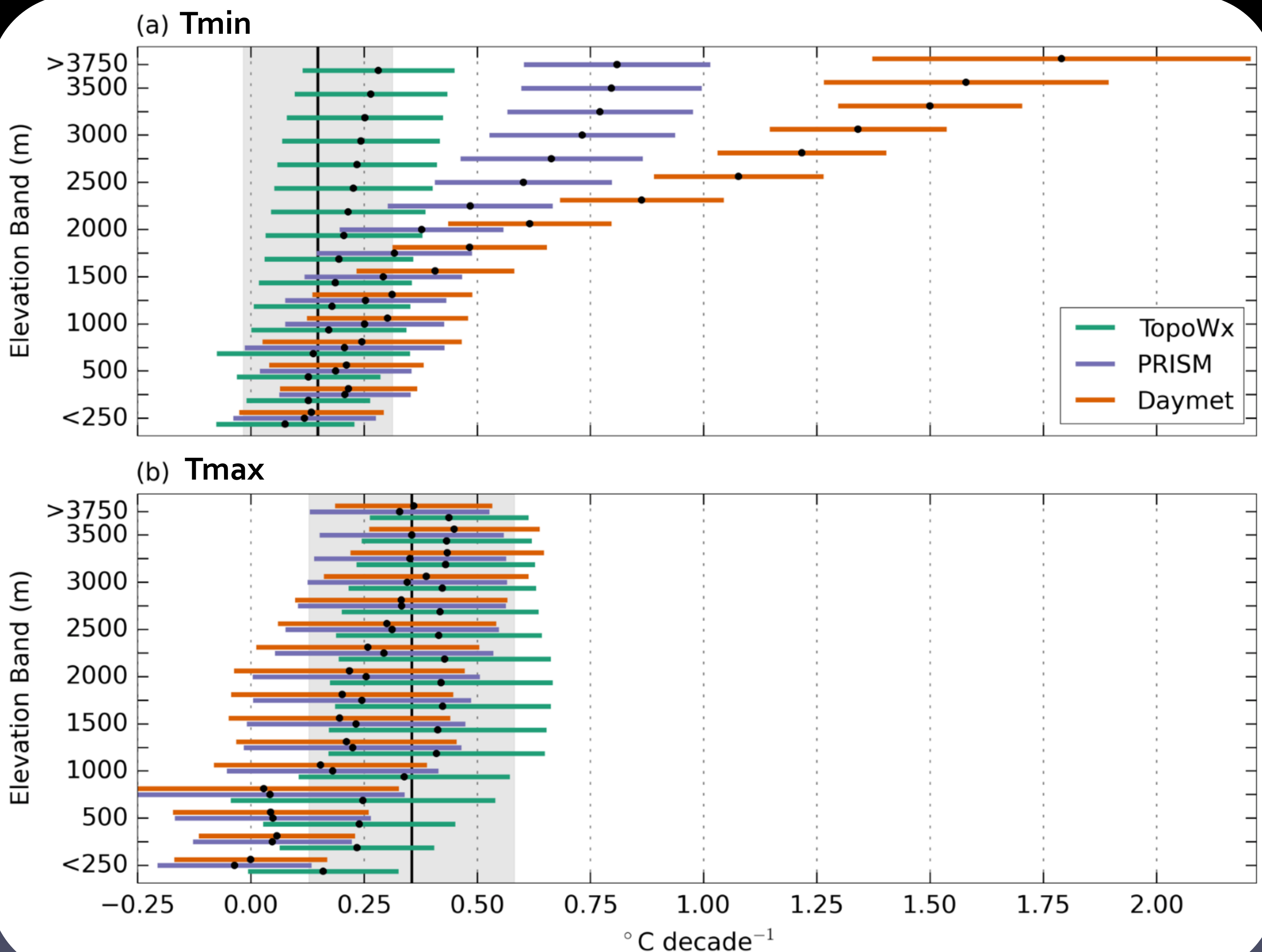
1981-2012 Annual Temperature Trends



1981-2012 Annual Temperature Trends

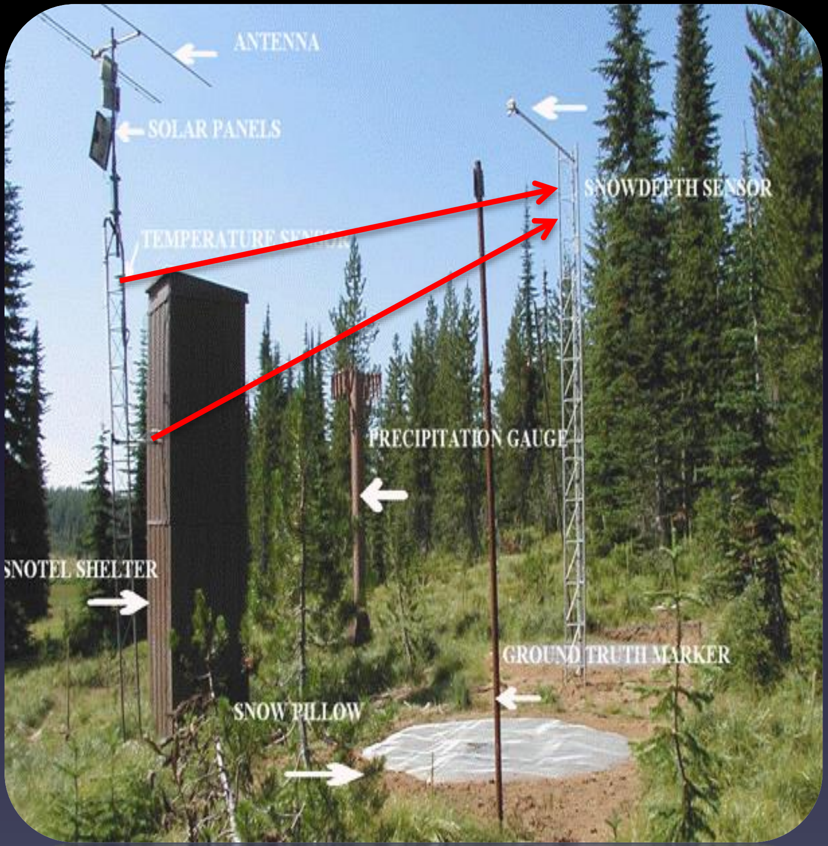


1981-2012 Annual Temperature Trends



SNOTEL Station Changes

- **Mid 1990s to mid 2000s**: field campaigns conducted to standardize SNOTEL temperature sensors.
- Sensors moved to new standardized meteorological data collection tower at each site.
- Changes in:
  - Sensor type
  - Radiation shields
  - Height



http://www.nrcs.usda.gov/Internet/FSE_MEDIA/nrcs144p2_039763.gif

Julander, R. P., Curtis, J., & Beard, A. (2007). The SNOTEL Temperature Dataset (p. 12). Salt Lake City, UT.

Conclusions

Conclusions

TopoWx contributes 3 main advancements to topoclimatic temperature interpolation:

1. An improved representation of interdecadal and long-term temperature trends
2. An improved representation of complex temperature spatial patterns, particularly for Tmin
3. A spatial representation of uncertainty that accounts for both model goodness of fit and the geographical arrangement of stations

These advancements were made through:

1. The use of previously developed homogenization procedures
2. Remotely sensed land skin temperature as an auxiliary predictor of topoclimatic air temperature
3. An unique implementation of moving window regression kriging

Conclusions

- Topoclimatic temperature datasets commonly used for climate impact analyses in the western U.S. are not robust to station inhomogeneities and subsequently contain spatially structured warm and cold trend biases

- Widespread systematic inhomogeneities in the SNOTEL network have artificially amplified an elevation-dependent warming signal across much of the western US, and have significantly biased trend estimates from widely used climate data products

- In the context of a warming climate, this artificial amplification of mountain climate trends has likely compromised our ability to accurately attribute climate change impacts across the mountainous western US.

Thank You

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Oyler, J. W., S. Z. Dobrowski, A. P. Ballantyne, A. E. Klene, and S. W. Running (2015), Artificial Amplification of Warming Trends Across the Mountains of the Western United States, *Geophys. Res. Lett.,* doi:10.1002/2014GL062803.

Questions?

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http://ntsg.umt.edu/project/TopoWx